Response to Referees comments:

Characteristics and causes of natural and human-induced landslides in a tropical mountainous region: the Rift flank west of Lake Kivu (DR Congo)

October 14, 2022

The authors would like to thank the editor and the two reviewers for their interest in our work and the relevance of their comments. Once again, we thank them for their appreciation of the quality of the work. We have taken into account these comments which revealed certain weaknesses in the presentation of our work. We note that reviewers #4 and #5 were not the reviewers involved in the first round of proofreading. We also note that Reviewer #5 is the one asking for a major revision. We also note that this reviewer does not want to proofread the new version of the revised manuscript. We hope that by showing here that the reviewer#5's comments could be easily addressed by small rephrasing/bringing some extra details, a third round of review will not be called. Indeed, with these two rounds of reviews (3 minor revisions/2 major) we have demonstrated that our work is sound both in terms of method/approaches and in terms of results/discussion. Most comments where associated with asking extra information.

On the specific concern that your also raised about the self-citation, we have removed whenever possible referencing to our work. Nevertheless, we want to recall that research on landslides in the tropics in general is very limited and it is especially so in Africa where the state of the art in the topic is unfortunately often associated with the work of the co-authors.

Our answers to the reviewers' comments are presented as follows: the reviewers' comments are shown in **black**; the answers are text in ***blue italics***. And the revised texts are in **green**. The lines of the final manuscript are shown in **purple**, while the lines of the manuscript with the tracked changes are in **orange**.

Contents

I. Reply to Referee #4

The authors presented a two-folded paper dealing with, on one hand, the redaction of landslide inventory through visual interpretation of aerial photos and google Earth imagery, and on the other hand, the landslide susceptibility mapping through Logistic Regression.Both the procedures are carried out with standard practices, and in general the paper do not present any particular novel content, however the analyses are clearly conducted and rigourously and critically discussed. Moreover, the environmental setting and the social implications in the territory make this paper a fair contribution in the landslide studies field.

We appreciate that the reviewer understands that our work is not method-oriented. In our goal to study landslide processes in the context of human-induced environmental changes, we use several classical key methods; logistic regression being one of them and used together with frequency-size statistics and frequency ratio.

1.1. General comments

Before the final publication I have some concerns and some comments:

- First of all, I do not find the title very reflective of the aim of the paper. I would try to be more specific on that.

We agree that a more specific title can be proposed. We now have: "Characteristics and causes of natural and human-induced landslides in a tropical mountainous region of Africa"

- The introduction section is pretty synthetic and I find that a more solid comparison with the state of the art should be done, with more recent papers (dealing with use of remote sensing or modern technologies for the inventory part, and with machine/deep learning for the susceptibility, for instance). Moreover, I would move section 1.1 in another chapter, since it is the descritiption of the study area, not an introduction. Moreover, this section needs a better geomorphological description of the area.

We have modified the introduction in order to better support our visual-based approach for the building of the multi-temporal regional inventory of landslides; which is the key aspect of this research. For the susceptibility focus, however, we have not included such a section as this is only *one of the three key (and classical) methods (together with frequency size and frequency ratio) that is used for the landslide process analysis. In addition, as stressed earlier, the originality of our work is not framed around methodological achievements; we therefore do not want to insist on those aspects in the introduction.*

The main changes in the introduction are in lines **L58-64 / L58-64**.

We have moved section 1.1 to a new numbered section 2 and adapted the subsequent numbering accordingly. That was an oversight.

L58-64 / L58-64: New methodologies have been proposed in the past years to automatically map landslides with the use of, for example, Earth Observation data and machine learning (e.g. Prakash et al. 2021). However, such automotic approaches only perform well with recent landslides with a clear spectral signature. Futhermore, they are not always well adapted to an accurate understanding of the processes (Jones et al., 2021), especially when the landscapes are complex and highly influenced by human activities (Jacobs et al., 2018). The need for a visual identification of landslides is even more important when the movemets that are studied are older and have occurred at an unknow period of time, much before the availability of sattelite images (Pánek et al., 2021).

> - In section 2.1 authors are claiming to estimate landslide depth through visual analysis. Could you please explain how this procedure is based? through which geomorphological features? How a 5 m depth can be estimated through visual interpretation?

The paragraph has been rephrased in order to better explain this depth estimation. We stress that this is based on a robust field-based expertise and validation.

L177-190 / **L180-194**: The estimation of the depth of a landslide is important when the role of LULC is to be considered; shallow landslides being much more sensitive to the vegetation characteristics than deep-seated landslides (Sidle and Bogaard, 2016). In the literature, a landslide is usually defined as shallow when the depth of its surface of rupture ranges between 2 to 5 m (Keefer, 1984; Bennett et al., 2016; Sidle and Bogaard, 2016). Here, landslides with a depth < 5 m were considered as shallow. This criteria is based on the numerous field observations in the region that show that regolith can easily develop over a depth of several meters and that trees often show deep rooting systems. Following the approach of Depicker et al. (2020) and Dewitte et al., (2021), The distinction between deep-seated and shallow landslides was made by visually estimating the relative landslide depth from © Google Earth and the 5 m resolution TanDEM-X hillshade images. Extensive in situ-field observations of several hundreds of recent landslides where then carried out to valid the assessment. The landslides occurring in mining and quarrying sites were all classified as mining landslides. A specific attention was also given to the landslides occurring along roads. Mining and road landslides are assumed to be related to important anthropogenic changes in the topography. Once they have occurred, field observations show that these landslides are commonly reworked and often further excavated. Therefore, for these two types of landslides, their depth was not assessed.

- Section 2.3, first paragraph: I think this section could be rewritten to make it more sound and coincise.

The paragraph has been rephrased; we mainly left out the reference to our study area.

L258-260 / **L-265-267**: Landslide susceptibility approaches are commonly used to determine the factors that control the occurrence of landslides. There are numerous approaches which are more or less complex in terms of modelling implementation, data needs, and result interpretability (Reichenbach et al., 2018).

- Logistic regression and frequency ratio have been applied on a splitted dataset of landslides, selecting on one hand the shallow ones, and on the other hand the deep-seated ones. This was made including both fast- and slow-moving landslides? Or without any distinction between the type of landslide and the material involved (i.e., rockfalls and debris flow)?

We have brought extra information about this, mostly in Section 3.1 (see lines **L204-206** / **L208-211***). We also better insist that we carry out our analysis with landslide categories instead of landslide types. We have made sure to adjust the text to this differentiation.*

L204-206 / **L208-211**: We performed this analysis separately for five categories of the inventory considered together or in isolation: all landslides, old and recent deep-seated landslides, shallow landslides, mining landslides and road landslides (see Section 3.1)..

- Section 3.1, first and second line. The sentence does not sound correct or I'm not getting the message?

We have simplified the sentence and move some of its information (that was more associated with a discussion) to line **L378-380** / **L397-400** *at the start of Section 4.1. (Results)*

L378-380 / **L397-400**:… Overall, we mapped 2730 landslides (Fig. 3a; Table 2). The landslides are diverse in terms of size, age and type (Fig. 4). The inventoried landslides cover ~3 % of the study area. The largest landslide is an old and deep-seated complex movement (426 ha), while the smallest detected landslide is a shallow debris avalanche (16 m^2).

Figure 4, if one of the pictures is showing any cluster displayed in the inventory, please mention it in the caption.

We have indicated that Figure 4a shows part of the clustered event 2 landslides in Figure 3a.

L441 / L463-464: … the image illustrate a part of the landslides clustered event 2 shown on Fig. 3a) …

Section 4.4, lines 632-633. Landslide can be favoured by road cuts, not only in the region, but worldwide. Please mention some case outside from your study area. In general the paper is full of self-citations and I'm not pretty sure they are all necessary.

We have added some references that were already used in the introduction.

With respect to the self-citation, we would like to recall that we are among the very few to study landslides in data scarce tropical environments, especially in Africa. Discussing our results with respect to the state of the art automatically implies some self-citation. We however would like to make sure that this is not perceived as such and whenever possible we have reduced reference to our work.

L674-676 / L704-706: … as observed not only in the region (e.g. Kubwimana et al., 2021), but worldwide (Froude and Petley, 2018; Sidle et al., 2006; Brenning et al., 2015; Arca et al., 2018; McAdoo et al., 2018; Vuillez et al., 2018; Muñoz-Torrero Manchado et al., 2021; Tanyaş et al., 2022); …

II. Reply to Referee #5

The theme addressed in the manuscript "Natural and human-induced landslides in a tropical mountainous region: The Rift flank west of Lake Kivu (DR Congo)" by Mateso et al., is an interesting and relevant study that explores how landslides occurrence since the late 50's of the last century is impacted by anthropogenic changes related to forest cover, roads, and mining activities in a rural tropical mountainous region under high anthropogenic pressure. Nevertheless, the manuscript, presents some aspects that should be better addressed. These are detailed described in the Specific Comments and Technical Comments sections.

The authors thank the reviewer for taking the time to read the manuscript in detail and to evaluate its content. We also thank him/her for the relevance of the comments that we were able to address in our revived version.

2.1. Specific comments

1) Are some of the inventories used by authors covering landslides trigger by rainfall and by earthquakes. That should be turned clear in the landslide inventory section. In addition, the

classification of landslides as mining and road landslides despite their depth and type is not the most adequate and constrain possible explanations for their occurrence.

*For the recent landsides, i.e. those that have occurred in the last 60 years (the historical aerial photographs being used for this discrimination), rainfall is the only triggering factor that we have identified. This is clearly mentioned in lines **119-148** / **121-151** in section 2*

*For the old landslides, as we are in a rift context where seismicity is present, we cannot exclude that some of the landslides in the inventory are associated with a seismic trigger. This is discussed in lines **119-148** / **121-151** in section 2.*

In section 3.1 about the inventory of landslides, we made it sure that it is repeated briefly (see lines **L151-155** /**L154-158***). However, overall, we would like to recall that the goal of our research is not to look at the triggers, but at the causes of the landslides. Following the advice of reviewer 1 we have made it clearer from, for example, the title.*

L151-155 /**L154-158:** The landslide inventory is a significant update of the inventory compiled by Depicker et al. (2020) who used only © Google Earth imagery for mapping the features whatever their type, age and rainfall, seismic or non-triggered origin as explained in Section 2. Since the focus of Depicker et al., (2020) was to study landslides over a much larger region than the one of the present research, their inventory was built on a limited search-time on our study area and without any field survey.

With respect to the adequacy of the classification of the mining and road landslides, we would have appreciated some orientation. The comment does not really help us understand how we could improve our inventory. However, it is important to keep in mind that for both categories of landslides, we observed that their topography is very altered by the road and mining contexts. In addition, very often, road and mining landslides are used by locals as material sources, which can lead to altered morphology and behavior. Lastly, making sub-categories among road and mining landslides would reduce (if not hinder) the statistical analysis as we would fall short of having enough information. We therefore believe that our analysis with this classification scheme is the most appropriate one to serve our research objective. We have brought extra information in lines **L188-190** / **L192-194** *to explain this.*

L188-190 / **L192-194**: … Mining and road landslides are assumed to be related to important anthropogenic changes in the topography. Once they have occurred, field observations show that these landslides are commonly reworked and often further excavated. Therefore, for these two types of landslides, their depth was not assessed.

2) What this work brings differently from the works of Depicker and co-authors for example?

This work is different from that of Depicker et al. 2020 in many ways:

- *Depicker et al. (2020) used only Google Earth imagery with a limited time search as their goal was to look at landslide regional trends for a much larger region than our study area. Here, we have spent much more time on this task to identify as much landslides as possibe.*
- *We have achieved intense field investigation, visiting the region six times and validating more than 700 landslides over an area that represent 20% of the study area. Considering the remoteness of the region as well as its safety concerns, this is a achievement that we considered exceptional.*
- *In addition to Google Earth imagery, we have used 5 m resolution TanDEM-X DEM derived hillshade maps as well as hundreds of historical aerial photographs. It allow us to better discriminate between the depth of the processes as well as their timing.*
- *We have made differentiation between the landslide types, and grouped them in several natura and human-induced categories. .*

Overall, our inventory contains 3 times more landslides than the inventory of Depicker et al. (2020). That information on the inventory can be found lines **L538-540 / L567-569**, *section 4. We have also in some parts improved the text to make sure that it is well understood that our research brought a significant and unprecedented new dataset. See lines* **L151-155** /**L154-158.**

L538-540 / L567-569: Despite its high precision, and the fact that with more than 2700 mapped landslides we have identified more than three times as many features as in the inventory of Depicker et al. (2020), we are aware that the dataset is still incomplete..

L151-155 /**L154-158:** The landslide inventory is a significant update of the inventory compiled by Depicker et al. (2020) who used only © Google Earth imagery for mapping the features whatever their type, age and rainfall, seismic or non-triggered origin as explained in Section 2. Since the focus of Depicker et al., (2020) was to study landslides over a much larger region than the one of the present research, their inventory was built on a limited search-time on our study area and without any field survey.

The work of other co-authors (Depicker et al., 2021a, 2021b; Dewitte et al., 2021) was either based on Depicker et al (2020) or on information that helped us to explain and discuss the regional context (Monsieurs et al., 2018a, 2018b, Dewitte et al., 2021); this latter information being not used as dataset in our research

3) If I understood well only exists aerial photographs from late 50´s of the last century and from 2016 land cover ESA model. How authors stablished the correlation between landslides that occurred outside the time frame of these two land cover images (part of the landslides are

dated from 2005-2019 images) and the predisposing terrain conditions related with forest cover?

This is, in each part of this 60-year period occurred the forest loss, forest gain? For example (L. 208-218) how can someone interpret based on figure 2a that in 1955-58 48 % was already deforested. It means that the entire area was covered with forest before? The comparison only allows to compare land use cover changes between the two-time frames. I strongly believe that these limitations should be carefully considered and the dynamic component revised by authors.

First of all, as explained in lines **L96-97** */* **L97-98**, *the natural vegetation of the region is forest (Nzabandora and Roche, 2015). In addition, it is known that the region was already deforested for quite some time along the major road axes present in the 1950's (Depicker et al., 2021b). We have rephrased and added information in lines* **97-98 / 98-99** *to make sure that it is easily understood.*

L97-98 / L98-99 : The roads built during the late 19th and first half of the 20th centuries played a key role on further expanding this (Aleman et al., 2018).

Indeed, for the pre-satellite era, historical photographs from the 1950's are the only existing source of information for this region. We have rephrased the text to make sure that it is clearly understood. We have also provided extra information on our justification for the use of the ESA dataset. See lines **L234-237 / L238-241**.

L234-237 / L238-241: This satellite-based product has an accuracy of roughly 86 % in the region and has demonstrated its relevance in another study on landslides (Depicker et al., 2021). Note also that between 2016 and 2019, i.e. the date that corresponds to the most recent images in Google Earth used for the inventory, very little forest cover changes were observed.

In section 3.1 (lines **L151-155 /L154-158***) we explain that the goal of our research is to complement the analysis conducted by Depicker et al. (2021b; see section 2) that focused on the impact of deforestation on shallow landslides over the last 20 years. Here, we therefore reconstructed the forest dynamics over the last ~60 years (Section 3.2). Depicker et al. (2021b) used satellite-derived products and could work on a yearly base. Here, we cannot do that has we only have two temporal frames. We have brought extra information in lines* **L232 / L236-237** *to make sure that it is better understood.*

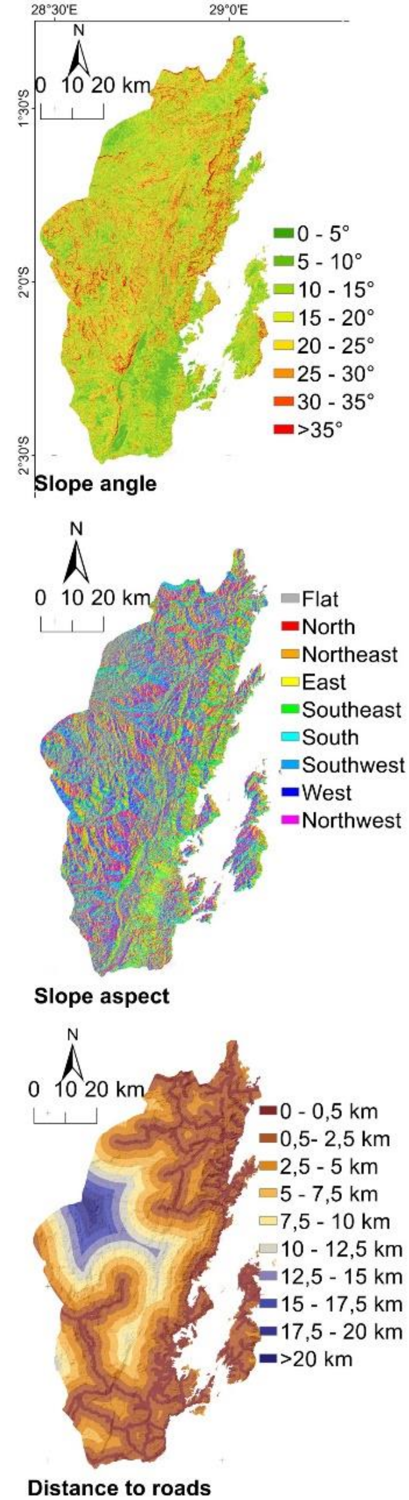
L151-155 /L154-158: The landslide inventory is a significant update of the inventory compiled by Depicker et al. (2020) who used only © Google Earth imagery for mapping the features whatever their type, age, and rainfall, seismic or non-triggered origin as explained in Section 2. Since the focus of Depicker et al., (2020) was to study landslides over a much larger region than the one of the present research, their inventory was not only built on a limited search-time on our study area but, also, without any field survey.

L232 / **L236-237:** …these photographs being the only existing pre-satellite era source of information.

4) A composed figure with the predisposing factors should be considered by authors

In the main text of the manuscript, we want to give priority to figures that show significant results. In addition, we provide already in Sections 2 and 3.2 as well as in figures 1 and 2 quite a significant amount of information on the environment that we study. Therefore, we added this suggested figure as supplementary material. Reference to this figure is made lines **L283-285** / **L295-297**.

L283-285 / **L295-297**: The purpose of this research is to examine the predictor variables (See supplementary Figure 1 for the predictor variables not displayed in the main manuscript) that contribute to the susceptibility of the different landslide categories.



5) In the methods section authors should clearly describe the susceptibility modelling strategy and with which landslide inventory partitions intend to validate the susceptibility maps. For example, validate the susceptibility maps with road and mining landslides and why.

We have rephrased sentences and added extra information in Section 3.3 to improve the method section. For example, in Lines **270 /281** *we insist on the fact that we look at the categories of landslides defined in section 3.1.*

L270 /L281: The analysis was carried out according to the five categories of landslides defined in Section 3.1.

For the validation of the susceptibility maps with road and mining landslides, this is explained Lines **L474-479 / L497-503***:"Depicker et al. (2020) assessed the impacts of the size of the landslide training dataset to calibrate a landslide susceptibility model. They showed that the quality of a susceptibility assessment is questionable if the number of landslides is too small. In view of the low number of recent deep-seated, mining, and road landslides in the present study (Table 3), we did not calibrate susceptibility models from these three types of landslides. Instead, we tested these inventories against the two susceptibility models computed from the shallow and/or old deep-seated landslide datasets, from which we could derive prediction rates (Fig. 7)".*

6) In the discussion section, please address better the possible bias that could overcome from the resampling of predictor variables for the SRTM resolution

Our choice of using this resolution was clearly justified in the former version. Now we have rephased this part to improve its understanding. In lines **L316-318 / 330-332** *we say the following:*

L316-318 / 330-332: Prior to analysis, the non topographically-derived predictor variables were resampled at the resolution of the SRTM DEM data; a resolution that is commonly used is many susceptibility analyses (Reichenbach et al., 2018) and that provided the best results in similar regions (e.g. Jacobs et al., 2018).

Since we are analyzing thousands of landslides, we are looking at patterns and trends, not at characteristics of individual landslides. We therefore believe that using a resampled lithological information that provides actual information at a scale of 1/500,000 does not have an impact on our outputs. Similarly, lowering the resolution of the LULC datasets is expected to have no impacts.

Since uniformizing dataset at the resolution of SRTM data is a very common practice, we believe that such an issue does not need to be discussed in the specific case of our regional analysis.

2.2. Detailed comments

L. 54: I agree with authors regarding deep-seated and shallow landslides differentiation but a discussion regarding the type of landslide is also acknowledge in this introduction section. The same should be better addressed in

In addition to rephrasing in the introduction (lines 48-49; line 53), we have improved the text at several locations to make sure that shallow and deep-seated landsides are here considered as 2 categories of processes, where several types of movements are present. In section 4.1 (lines 439-453) we explain this in detail.

L. 179-185: The classification of the landslide type in mining and road landslides does not seem the most interesting. Even so, what type of landslides are mapped? In addition, it's important to earlier in the manuscript to clarify which type of landslides authors are used to assess susceptibility. Only slides? Adjust terminology along the manuscript accordingly.

We agree that we needed to make a clarification on the terminology. Section 4.1 (lines **L380-400** */* **L399-420***) details the types of landslides we have identified and explains well how they have been grouped into five categories for the frequency size, susceptibility and frequency ratio analyses. This grouping into categories is now also explained in the abstract (line* **21***/* **21***) as well as in other places in the text (lines* **204** */* **208-209***;* **270** */***281***).*

L380-400 / L399-420: The landslides are grouped into five categories (Fig. 3a; Table 2):

- Old deep-seated landslides represent 45,5 % of the inventoried landslides and cover 93 % of the total landslide affected area. Most of these landslides are of the rock slide type. Rock avalanches, although much less frequent, are also present. Rockfalls can be associated with the presence of the main scarps of these old landslides. However, they have not been considered in the inventory and the subsequent analysis;
- Shallow landslides represent 40.4 % of inventoried landslides, but represent only 2.7 % of the total affected area. Most of these landslides are of the debris avalanche type. These landslides are all recent and clearly associated with rainfall. The landslides clustered events all fall in this category;
- Recent deep-seated landslides represent a small percentage of landslides (5.8 %) but cover an area (2.9 %) similar to shallow landslides. Most of the landslides are of the slide type. Their trigger, when identified, is associated with rainfall;
- Mining landslides (that also include quarrying landslides) represent 5.6 % of the inventoried landslides and cover 1.2 % of the total landslide affected area;
- Road landslides: the inventory shows that 115 landslides are located within 50 meters of roads. 60 of these landslides are shallow, 13 recent and deep-seated, 35 old and deep-seated, and 7 are mining landslides. Only the shallow and recent deep-seated landslides were

classified as road landslides; i.e. a total of 73 landslides The old deep-seated landslides located close to roads were retained in the old deep-seated landslide category because their timing is likely to precede road construction. The mining landslides were also retained in their respective category.

L21/ **L21:** …that we group into five categories…

For the use of the categories road and mining landslides, we refer to our reply to specific comment 1 where this issue was already raised and where we explain its relevance in the context of this research.

In section 2.1 a description of the base inventory constructed by Depicker et al (2020) is welcome. For example, what landslide inventory period is covered by the work of Depicker et al (2020)?

We have added information to better clarify the added value of our work as compared to that of Depicker (see lines **151-155** */* **154-158***). We also bring a more detailed answer with respect to specific question 2.*

L151-155 / **L154-158:** The landslide inventory is a significant update of the inventory compiled by Depicker et al. (2020) who used only © Google Earth imagery for mapping the features whatever their type, age and rainfall, seismic or non-triggered origin as explained in Section 2. Since the focus of Depicker et al., (2020) was to study landslides over a much larger region than the one of the present research, their inventory was built on a limited search-time on our study area and without any field survey.

L. 142: Please address better what the mean of "differentiated between the processes"

We have rephased this sentence (lines **L155-157** / **L158-160***) as the following: "Moreover, in our research we differentiated between the types (according to the updated Varnes' classification proposed by Hungr et al. (2014)) and timing of landsliding"*

L155-157 / **L158-160**: Moreover, in our research we differentiated between the types (according to the updated Varnes' classification proposed by Hungr et al. (2014)) and timing of landsliding. We strongly relied on three image products:

L. 154-156: For authors what is consider a recent landslide? It is a landslide with less than 60 years? How distant in time is possible to relate landslides with a date of occurrence. This point regarding the definition of old and recent landslides, concerning landslide age needs to be clarified in my opinion.

This definition of landslide "age" is clear to us and is provided here (lines **L169-171** */* **L172-174***):* *"The historical aerial photographs allowed to differentiate between old deep-seated landslides (i.e. landslides with an unknown time of origin and already present on the photographs) and recent deep-seated landslides that have occurred during the last 60 years (i.e. after the acquisition of the photographs)."*

L. 162-165: the visual estimation of landslide depth is discussable. Please turn clear.

This was also commented by reviewer 4. Here is our reply: "The paragraph has been rephrased in order to better explain this depth estimation. We stress that this is based on a robust field-based expertise and validation. "

L177-180 / **L180-194**: The estimation of the depth of a landslide is important when the role of LULC is to be considered; shallow landslides being much more sensitive to the vegetation characteristics than deep-seated landslides (Sidle and Bogaard, 2016). In the literature, a landslide is usually defined as shallow when the depth of its surface of rupture ranges between 2 to 5 m (Keefer, 1984; Bennett et al., 2016; Sidle and Bogaard, 2016). Here, landslides with a depth < 5 m were considered as shallow. This criteria is based on the numerous field observations in the region that show that regolith can easily develop over a depth of several meters and that trees often show deep rooting systems. Following the approach of Depicker et al. (2020) and Dewitte et al., (2021), The distinction between deep-seated and shallow landslides was made by visually estimating the relative landslide depth from © Google Earth and the 5 m resolution TanDEM-X hillshade images. Extensive in situ-field observations of several hundreds of recent landslides where then carried out to valid the assessment. The landslides occurring in mining and quarrying sites were all classified as mining landslides. A specific attention was also given to the landslides occurring along roads. Mining and road landslides are assumed to be related to important anthropogenic changes in the topography. Once they have occurred, field observations show that these landslides are commonly reworked and often further excavated. Therefore, for these two types of landslides, their depth was not assessed.

L. 170-171 "by selecting representative areas with various landslide and landscape characteristics". How the representative areas are selected and how are these areas are defined? Which percentage of study area was covered by field survey? The use of the criteria "various landslides" should also be clarified.

We have clarified this part of the text explaining that 20% of the area was surveyed. See lines **L194-197** / **L198-201**.

L194-197 / **L198-201**: The work was carried out by selecting representative areas with various types of landslides and areas with less or no landslides. These areas, that cover a total of ~20% of the region, were selected based on different landscape characteristics (lithology, slope, LULC), while taking into account accessibility and safety issues that prevent to access many places (Jaillon, 2020).

L. 188: Include in the manuscript the criteria that define a landslide event.

We now provide a clearer definition. See lines **L129-131** / **L131-134**.

L129-131 / **L131-134**: A catalogue of > 150 accurately dated landslide events, i.e. landslides that can be clearly associated with a common well-defined triggering rainfall event over the same area, was compiled for the NTK Rift for the last two decades. .

L.191-192: why a maximum of 30 landslides per cluster? The concept of minus event, containing other isolated landslides (L. 193) was not perfectly clear to me.

This methodological choice is now better explained with respect to the statistical soundness of the analysis. See lines **L216-220** / **L221-224**

L216-220 / **L221-224**: Thus, for the shallow landslides susceptibility analysis (see Section 3.2), we retained a maximum of 30 landslides per cluster, randomly sampled in order to strengthen the statistical analysis and avoid overfitting. The choice of this selection is also guided by the concern to have at least the minimum of data required for training and validating the susceptibility models (Depicker et al., 2020).

L. 250: Is missing from the list of predictor variables the forest dynamics between 1955-58 and 2016

L288-290 / **L302-304**: *These are natural factors that influence landslide occurrence. Forest cover dynamics between 1955-58 and 2016 are presented among the anthropogenic predictors (see* **L302-303** / **L317-318** *and table 1).*

L. 237-239: The difference between shallow landslides and deep-seated landslides is relevant if landslides are of the same landslide type, e.g., slides. Authors made this explanation latter on the manuscript, but that should be turned clear earlier, in section 2.1. Moreover, how is selected one point (pixel) per landslide. The landslide susceptibility predictive power provides significant differences depending on the use of the entire landslide area for training the susceptibility model considering larger usually deep-seated slides or shallow slides (usually smaller in size).

Regarding your previous comment on this subject (2.2. Detailed comments), we have added information in section 3.1 to better explain this differentiation between processes and categories. We also clarify this better in section 4.1 (lines **L380-400** / **L399-420:** *).*

L380-400 / **L399-420:** The landslides are grouped into five categories (Fig. 3a; Table 2):

- Old deep-seated landslides represent 45,5 % of the inventoried landslides and cover 93 % of the total landslide affected area. Most of these landslides are of the rock slide type. Rock avalanches, although much less frequent, are also present. Rockfalls can be associated with the presence of the main scarps of these old landslides. However, they have not been considered in the inventory and the subsequent analysis;
- Shallow landslides represent 40.4 % of inventoried landslides, but represent only 2.7 % of the total affected area. Most of these landslides are of the debris avalanche type. These landslides are all recent and clearly associated with rainfall. The landslides clustered events all fall in this category;
- Recent deep-seated landslides represent a small percentage of landslides (5.8 %) but cover an area (2.9 %) similar to shallow landslides. Most of the landslides are of the slide type. Their trigger, when identified, is associated with rainfall;
- Mining landslides (that also include quarrying landslides) represent 5.6 % of the inventoried landslides and cover 1.2 % of the total landslide affected area;

Road landslides: the inventory shows that 115 landslides are located within 50 meters of roads. 60 of these landslides are shallow, 13 recent and deep-seated, 35 old and deep-seated, and 7 are mining landslides. Only the shallow and recent deep-seated landslides were classified as road landslides; i.e. a total of 73 landslides The old deep-seated landslides located close to roads were retained in the old deep-seated landslide category because their timing is likely to precede road construction. The mining landslides were also retained in their respective category.

We have rephrased this part where we explain how the point (pixel) per landslide is selected (Lines **L272-276** / **L284-288***). There we also justify this approach to avoid spatial autocorrelation as well as a temporal bias for the large and old landslides. .*

L272-276 / **L284-288**: The point is manually positioned in the central region of the visually delineated landslide’s source area to represent the conditions as close to reality as possible that cause its occurrence. In doing so we also avoid the selection of the highest point of the landslide that rarely corresponds to its initiation point (Dille et al., 2019). As stressed by Tanyaş et al., (2018), landsides growth with time. Therefore, considering one pixel per landslide instead of its whole source area allows to avoid a temporal-induced bias.

L.239: Please turn clear what is the centre of the landslide trigger area, this concept is not clear to me. Do you mean rupture zone, depletion zone, initiation area? Please, see my previous comment on this topic.

We now explain this in a clearer way. See lines **L271-272 / L284-286**. *Note that here we prefer the use of source area instead of depletion area.*

L272-273 / L284-285: The point is manually positioned in the central region of the visually delineated landslide's source area to represent the conditions as close to reality as possible that cause its occurrence.

L. 247-249: How spatial predisposing predictors allow to discuss triggering conditions? I apologize, but I think the description is too general and maybe it should be preferable to direct the explanation for preparatory conditions for landsliding.

This part makes reference to the key principles in tectonic geomorphology that are associated with interactions of tectonic, landscape and climate. We have rephrased the paragraph and added relevant references to support this statement. See Lines **L283-287 / L295-300**.

L283-287 / L295-300: The purpose of this research is to examine the predictor variables (See supplementary Figure 1 for the predictor variables not displayed in the main manuscript) that contribute to the susceptibility of the different landslide categories. As such we mainly investigate the causes of the landslides. Nevertheless, the predictors highlighted by the susceptibility analysis may also help to discuss triggering conditions since the tectonic, landscape and climate of a region are commonly interlinked (Whipple, 2009; Whittaker, 2012).

L. 270 – 272m. Authors mentioning that the few recent landslides observed along these roads confirm the assumption that the direct impact of the main roads on the occurrence of landsides is limited. This are not results? Move for the results section.

*This is an observation that can indeed be interpreted as results. However, that is an observation that is necessary to define our methodological choices. Since here we do not present yet specific results on the inventory, we prefer to leave this sentence here (***L307-309 / L321-323***).*

L. 287-292: I understand authors idea, but how much of these shallow landslides occurred along or near the fault zone? If authors are using the distance to faults to correlate with weathering, are not these weathering materials more prone for landslding? This should be better addressed.

We understand the relevance of your question. However, for the shallow slides, we have to keep in mind that the inventory is temporally biased. We explain our methodological choice in lines **L324-329 / L339-344***: ➔ For the analysis of deep-seated landslides, the predictor variables associated with anthropogenic activities were excluded. For the shallow landslides, the 'distance to faults' variable was also excluded. As explained earlier, the shallow landslide inventory represents a narrow time window of observation. As such, the spatial distribution of the shallow landslides could be biased by the stochastic pattern of the recent heavy rainfall events and anthropogenic disturbances rather than being the reflect of the longer-term impact of weathering conditions associated with seismicity."*

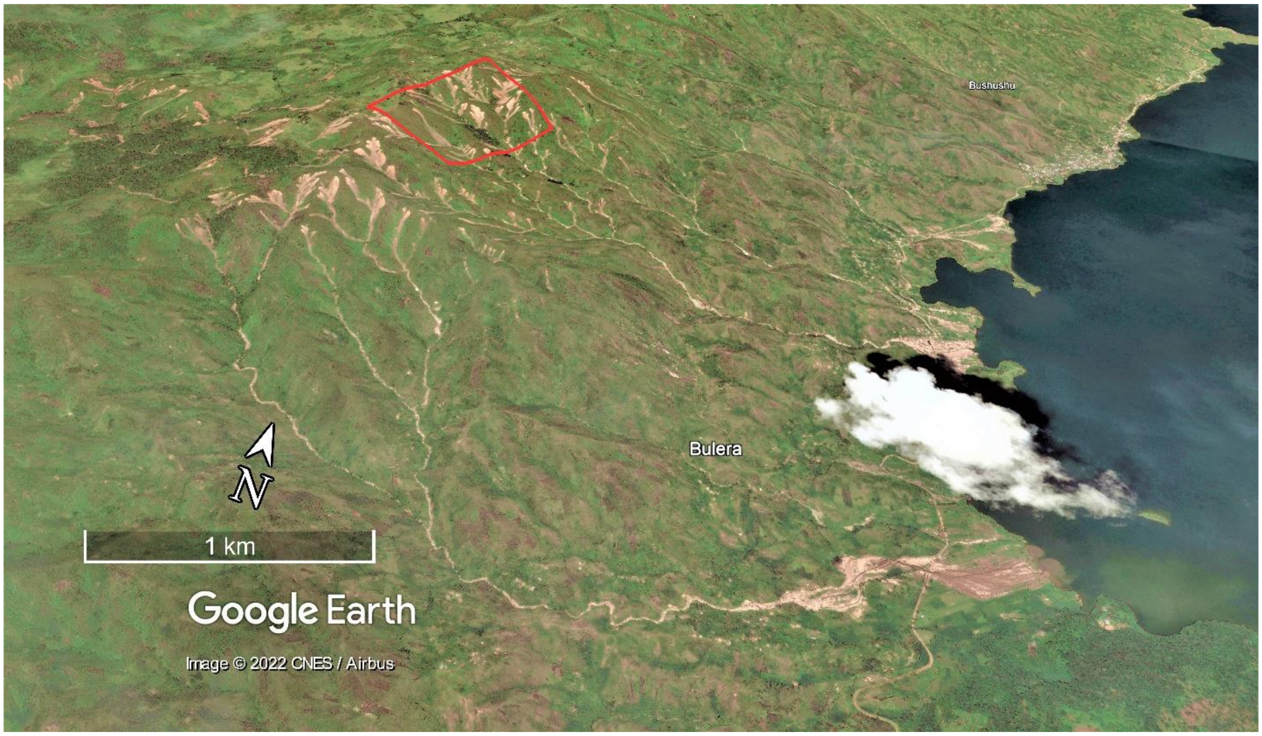
L. 355- Seven landslides are mining landslides? But this category is not related to road landslides? Are landslides classified in more than one category? L. 357-358: please avoid repetitions, the idea that road landslides include only the landslides located within 50 m of roads was already written above in the paragraph.

7 of the 115 landslides located with a 50 m buffer from the roads are mining landslides; these mining landslides being retained in their respective category. We have rephased this part to make sure that it is better understood. See lines: **L393-398** / **L414-420**.

L393-398 / **L414-420**: Road landslides: the inventory shows that 115 landslides are located within 50 meters of roads. 60 of these landslides are shallow, 13 recent and deep-seated, 35 old and deep-seated, and 7 are mining landslides. Only the shallow and recent deep-seated landslides were classified as road landslides; i.e. a total of 73 landslides The old deep-seated landslides located close to roads were retained in the old deep-seated landslide category because their timing is likely to precede road construction. The mining landslides were also retained in their respective category.

L. 367-372: how much of the 634 shallow landslides of the October 2014 rainstorm event occurred in the study area? Only 14? This was not clear to me. Where they occur specifically on the shores of Lake Kivu? The blue dots on figure 3 seems few for these 634 landslides mentioned.

The scale of the map does somehow bias our interpretation of the number of the identified landslides. Figure 4.a presents a rather small partial view of the landslide event 2 (see location in Figure 3) were more than 50 sources of shallow debris avalanches are identified. In the image below, this figure 4a view is localized within the whole area impacted by the landsides of this clustered event.



*As you can see from the figure above, there are not just 14 landslides, but 634. The text is quite clear (***L405-407** */* **L426-430***), the 14 landslides are those that were triggered before the major rainfall event of October 2014 and were subsequently reactivated during this event.*

L405-407 / **L426-430**: We identified several shallow landslides clustered events. One of the events is related to the Kalehe rainstorm of October 2014 (Fig. 3a: event 2; Fig. 4a) reported by Maki Mateso and Dewitte (2014). This rainfall triggered 634 shallow landslides, 346 of them being connected to talwegs and providing materials to 17 debris flows.

L. 388-390: 25% more deep-seated landslides were identified in the field but not used in the analysis to avoid biases due to overrepresentation. Are the predisposing conditions associated to these landslides like the ones used to assess landslides susceptibility?

If not, how good can be the predictive susceptibility map. Validating the produced landslide susceptibility map with those landslides could help answering this question.

*We visited 786 (i.e. 25%) of the landslides identified in the images. In addition, we identified only in the field alone an extra 126 landslides; these field landslides were not considered in the analysis to avoid bias and overrepresentation (***L421-429** */* **L443-451***). We have brought a little change to the original text that we believed clearly explained the issue. See lines* **L428** */* **L450***.*

L428 / **L450:**… extra 24% of observations (Table 3: see column FN).

L. 421: the fact that 72 % of the landslides are found in areas of forest loss really means that they occurred with that predisposing condition? These landslides occurred before or after the forest loss? The dates of the landslides not always match the date of the forest cover image.

Indeed, 72 % of the landslides have occurred in a deforested context. In lines **L236-237** */* **L240-241** *we have added an explanation to stress that between 2016 (the ESA most forest coverage used in this analysis) and 2019 (the most recent images from Google Earth sued for the analysis), no substantial change is observed.*

L236-237 */* **L240-241***:* Note also that between 2016 and 2019, i.e. the date that corresponds to the most recent images in Google Earth used for the inventory, very little forest cover changes were observed.

*Regarding the last part of your question, we have already answered that in your question 3 in specific remarks. You can refer to the following text in the manuscript (***L239-241 / L243-245***).*

L239-241 / L243-245: Knowing that the natural vegetation of the study area is forest (Section 2.1), in 1955-58, 42 % of the territory was already deforested (Fig. 2a). From 1955-58 to 2016, the loss of forest continued, the forest cover decreasing from 58 % to 24 % of the study area.

L. 462-463: The authors analysis conclude that shallow landslides are 2.5 times more likely to occur as deforestation increases? Please see my previous comment on this topic.

The 2.5 times comes from the logistic regression analysis, more specifically to the odds ratio (Table 5). We think that with the clarifications that we brought earlier, this is something that does not need to be further commented.

L. 473: This steep was not clear from the methods section. If the susceptibility model was produced for shallow slides, why validate it with mining landslides. It seems to me from figure 5b that mining landslides are closer to the characteristics of recent deep-seated landslides than to shallow slides. This validation with landslides datasets not used to construct the susceptibility maps is not clear from the methods section.

Your question has been answered above in question 5 (specific comments: **L474-479 / L497-503***). In the method section, the paragraph in lines* **L283-287 / L295-300** *has been added for clarification. Overall we believe the changes made throughout the text clarify many methodological aspects.*

L283-287 / L295-300*:* The purpose of this research is to examine the predictor variables (See supplementary Figure 1 for the predictor variables not displayed in the main manuscript) that contribute to the susceptibility of the different landslide categories. As such we mainly investigate the causes of the landslides. Nevertheless, the predictors highlighted by the susceptibility analysis may also help to discuss triggering conditions since the tectonic, landscape and climate of a region are commonly interlinked (Whipple, 2009; Whittaker, 2012).

L. 525-536: landslides in the permanent anthropogenic environment – what is the relationship between the short time for which the shallow landslides were inventoried in the study area and the fact that the study area was not altered by mechanized farming? When mechanized farming begins in the study area? Which terrain anthropogenic conditions lead to slope instability in these anthropogenic landslides. This should be better addressed.

Shallow landslides are known to disappear rather quickly from these tropical landscapes, sometimes in a matter of a few years (Dewitte et al., 2022). In addition, mechanized farming is known to accelerate such a process of landslide scar alteration. In our study area, as we have several images cover over the 2005-2019 period, we are confident that we have not a shallow landslide inventory biased by time-related disappearance. Furthermore, as said in section 2 and repeated here, there is no mechanized farming in our study area. A lot of background information to understand this paragraph is provided in the first paragraph of this discussion section 5.1, of which we have provided extra details (lines **L543 / L571-572***). We therefore believe that in this revised version of the manuscript the text that the reviewer highlighted in his/her comment does not need to be modified (lines* **L567-578 / L595-606***).*

With respect to the terrain anthropogenic conditions that lead to slope instability, at this regional level of analysis, only assumption can be made in a more or less robust way. That is the goal of our discussion.

L542 / L571-572: …although, here, since we have used several image covers from Google Earth, this issue should be nuanced.

L. 545: the model show that seismic activity play a dominant role in deep-seated landslide distribution in the study area – ok. Were all the old deep-seated landslides earthquake triggered, if not, are the terrain conditions of old deep-seated rainfall-triggered landslides like the previous ones?

In lines **L587-588 / L615-616***, we clearly say that the model suggests (we remain moderated with the use of "seem" in the sentence) a role of seismic activity on the occurrence of deep-seated landsides. Then we discuss this in lines* **L614-625 / L641-654***. We believe that the modifications that were brought at several places in the text to explain the potential role of triggering factors make now this paragraph easier to be understood. We therefore decided not to modify it.*

L. 592-593: the regional susceptibility model shows that deforestation is the most important factor. Again, and I apologize for my repetition, this is difficult to understand since landslide dates do not have a landcover photography that allows to stablish a direct relationships with landcover. This section of drivers for shallow slides should be better addressed concerning the relationship between forest cover type and landslides.

We believe that the modifications that were brought at several places in the text to explain the date of the landslides and the temporal aspects of LULC make now this paragraph easier to be understood. We therefore decided not to modify it

L. 615: why authors say that colluvium deposits result in a concentration of susceptible places. This is not clear to me. Please address better.

The availability of a certain minimum depth of colluvium is necessary for the occurrence of a shallow landslide. We have added information and a reference to support this. See lines **L655-657** / **L684-686**.

L655-657 / **L684-686**: This could be extra material available for the formation of landslides; the colluvium supply and a minimum depth of material being recognized as playing a key role in the occurrence of shallow landslides (Parker et al., 2016).

Section 4.4. Why should the produced susceptibility models validate the mining and road landslides: Are these two categories related to shallow or deep-seated landslides?

We have already explained better in the revised manuscript, based on earlier comments, that we do not aim to validate the susceptibility models with mining and road landslides. In addition, we have rephrased lines **L664-665** / **L694-695** *to better explain this.*

We have also better explained the reason why we cannot provide a depth criteria with the definition the mining and road landslides (lines **L188-190** */* **L192-194***). We also explain that there is not enough mining and road landslides to calibrate statistically-robust susceptibility models (lines* **L474-478** /**L497-502***: "Depicker et al. (2020) assessed the impacts of the size of the landslide training dataset to calibrate a landslide susceptibility model. They showed that the quality of a susceptibility assessment is questionable if the number of landslides is too small. In view of the low number of recent deep-seated, mining, and road landslides in the present study (Table 3), we did not calibrate susceptibility models from these three types of landslides. Instead, we tested these inventories against the two susceptibility models computed from the shallow and/or old deep-seated landslide datasets, from which we could derive prediction rates (Fig. 7).")*
).

Therefore, looking at how mining and road landslides are distributed on the two susceptibility models is an original way that we have found to analyze their distribution.

L664-665 / **L694-695**: The poor prediction rates of mining and road landslides when compared to the two shallow and deep-seated susceptibility models (Fig.7) shows that they respond to different environmental factors.
L188-190 / **L192-194**: Mining and road landslides are assumed to be related to important anthropogenic changes in the topography. Once they have occurred, field observations show that these landslides are commonly reworked and often further excavated. Therefore, for these two types of landslides, their depth was not assessed.

2.3. Technical comments

L. 58, L. 123: Monsieurs et al., 2018 and references therein along the manuscript: please check and indicate if the references to the work of Monsieurs et al., 2018 is 2018a or 2018b.

Well thanks for the remark, we have corrected **L132** / **L135** and **L135** / **L137**

L133 / **L135** and **L136** / **L139**: …Monsieurs et al., 2018b; …

L. 87: please check "altitude" or "elevation", If related with relief it should be elevation.

Thanks for the remark, we have corrected in lines L96 and L534.

L94 / **L95** and **L526** / **L555**: …elevation…

L. 203-205: Create an appropriate reference in the reference list for the work of Smets et al., to be submitted) and cite accordingly in the manuscript.

We have removed the reference to these authors.

L. 794 and L. 797 please indicate which reference is 2021a and 2021b

L849-853: Thank you for the remark, we have specified the two references

L838-842 / **L878-882**:
Heri-Kazi, A. B. and Bielders, C. L.: "Cropland characteristics and extent of soil loss by rill and gully erosion in smallholder farms in the KIVU highlands, D.R. Congo," Geoderma Reg., 26(May), e00404, doi:10.1016/j.geodrs.2021.e00404, 2021a.

Heri-Kazi, A. B. and Bielders, C. L.: Erosion and soil and water conservation in South-Kivu (eastern DR Congo): The farmers' view, L. Degrad. Dev., 32(2), 699–713, doi:10.1002/ldr.3755, 2021b.

Items not cited in the manuscript but present in the References list: L. 760: Trumbore et al 2019….; L. 773: Fisher et al 2012….; L. 779: Geenen 2012; L. 810: Kampunzu et al 1998….; L. 928: Vanacker et al 2003….; Hungr et al., 2014. Please check references/reference list and respective citation on the manuscript.

Trumbore is a co-author in the article by Drake et al. (2019) see **L101** */-***103**

L102 / **L103**: … construction (Musumba Teso et al., 2019; Drake et al., 2019).

We have added the citation from Fisher et al. (2012) see **L67** / **L68**

L68 / **L68**: …available on © Google Earth (Fisher et al., 2012), which are widely…

We have added the Geenen (2012) citation in the text, see **L90** / **L93**

L91 / **L92-93**: … artisanal and small-scale mining and quarrying (Van Acker, 2005; Geenen, 2012;…

The reference Kampunzu et al. (1998) has been added from the list of references.
L89 / **L90:** …fracturing (Kampunzu et al., 1998).

We have updated the Vanacker et al. (2003) citation in **L38** / **L39** and **L45** / **L46**.
L39 / **L39** and **L46** / **L46:** Vanacker et al., 2003;…

Hungr et al. (2014) have been well cited on the legend of Figure 4 see L447 and the reference has been put on the texts added on the article L166.

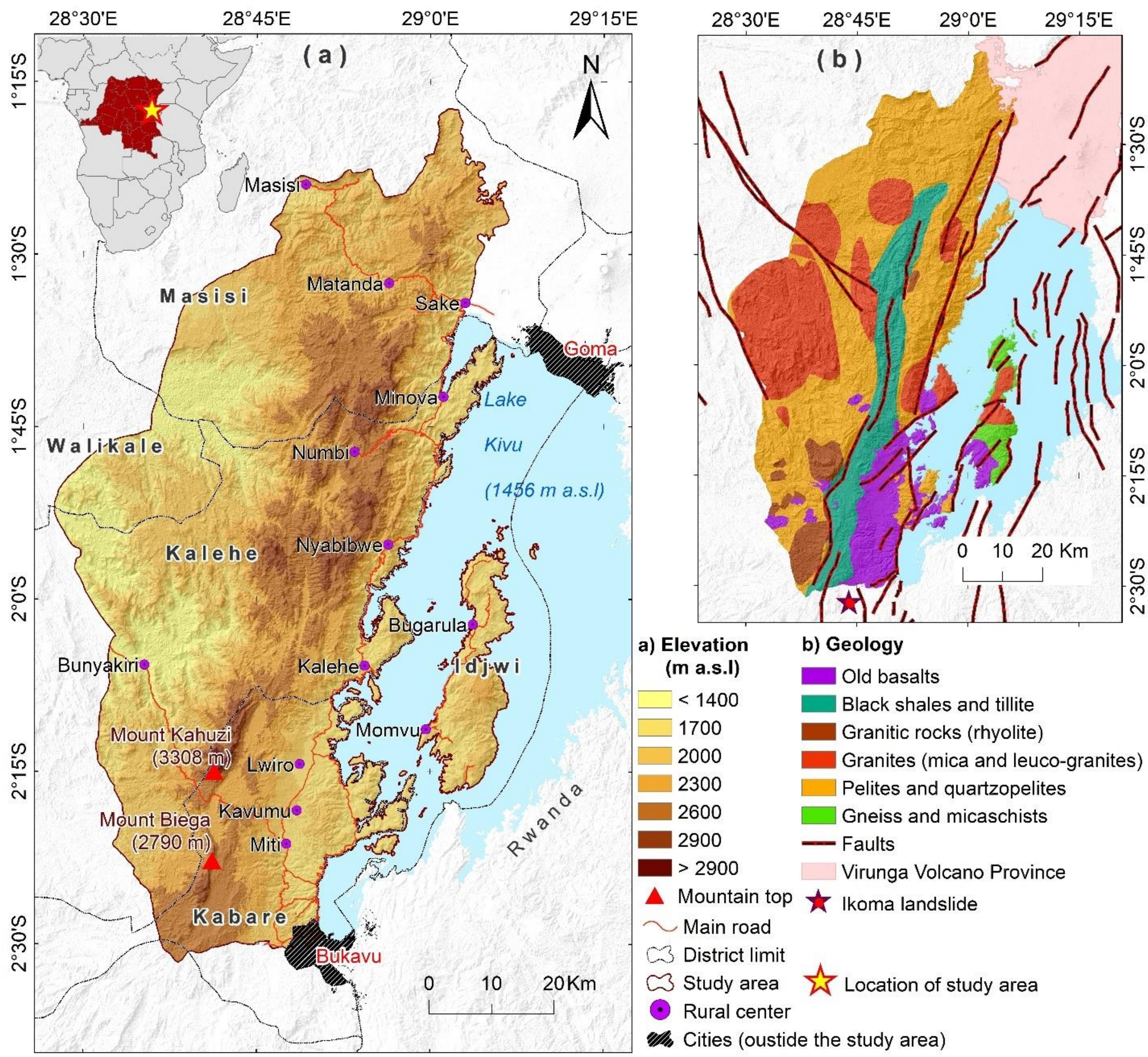
L156 / **L159**: … (according to the updated Varnes' classification proposed by Hungr et al. (2014) and timing …

L439 / **L461**: … Examples of landslide types (according to Varnes' new classification – Hungr et al., 2014).

2.4. Figures and Tables

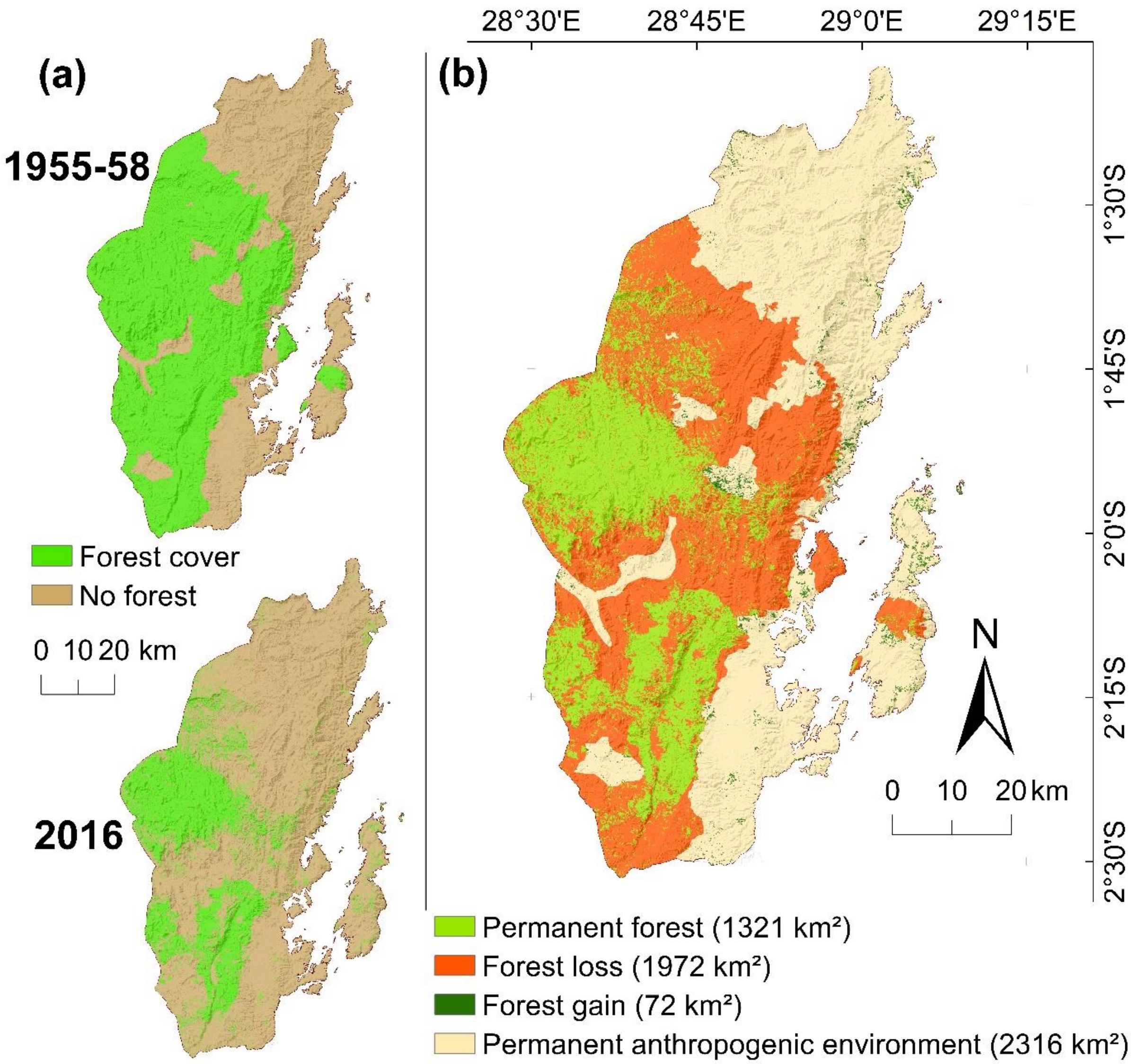
Page 3 – Figure 1: Check graphic representation of scale bars of maps 1a and 1b, uniformize and add bottom line in scale bar of map 1b. The same should be checked in all figures. Include in legend of figure 1a the meaning of the yellow star in the upper-right part of figure. It represents the location of study area?

The graphical representations of the scale bars in Figure 1 are corrected. We have included the location of the study area in the legend. See ***L106*** */* ***L108***



Page 6 – Figure 2: In figure 2a and 2b consider having the same legend for classes "no forest" in figure 2a and "permanent anthropogenic environments" on figure 2b, if representing the same class variable. The same for "Forest cover" in figure 2a and "permanent forest" in figure 2b.

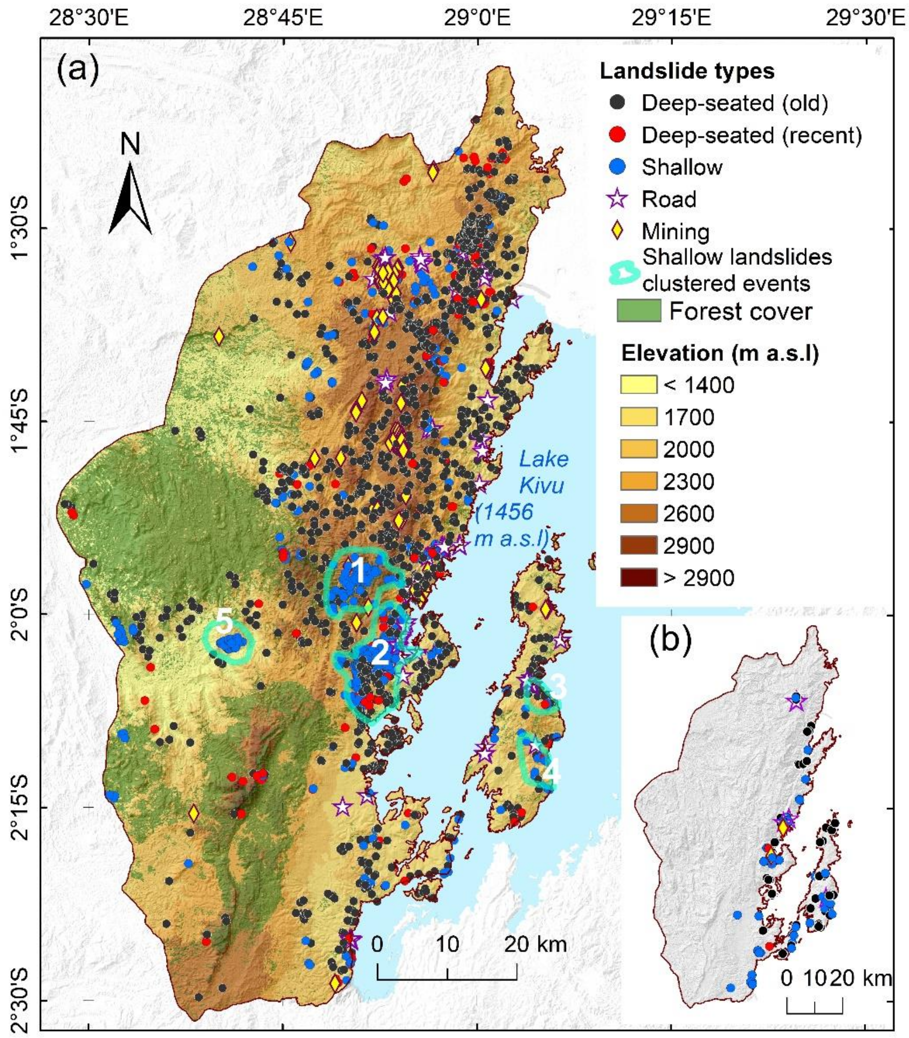
We have corrected the figure. **L253** / **L259**



Page 10 – Figure 3: Somewhere along the manuscript text clarify what criteria define a heavy rainfall event. Furthermore, the shallow slides associated to each cluster should be identified. Consider adding polygon lines (limits) grouping all the landslides for each event. Figure 3b include scale bar. The additional landslides identified only in the field could be associated with some of the rainfall events identified on figure 3a? Please turn clear along text.

Lines 132-138 provide a good explanation of what intense rainfall events consist of in our study area. We have added the polygons including all shallow landslides from a rainfall event (see Line ***L401*** */* ***L421****).*

We have added the scale bar for Figure 3b.
The © Google Earth images are well clear to map landslides related to these major rainfall events.



Page 17 – Figure 8: What the meaning of values above the vertical bars since they do not match with both right and left side bars. Is the frequency ratio score. Please adjust caption.

These are frequency ration scores. We have added some words to specify the meaning of these values L527

L520 / L548: The corresponding frequency ratio is shown for each class above the vertical bars.

III. References

Aleman, J. C., Jarzyna, M. A., and Staver, A. C.: Forest extent and deforestation in tropical Africa since 1900, Nat. Ecol. Evol., 2, 26–33, https://doi.org/10.1038/s41559-017-0406-1, 2018.

Arca, D., Kutoğlu, H. Ş., and Becek, K.: Landslide susceptibility mapping in an area of underground mining using the multicriteria decision analysis method., Environ. Monit. Assess., 190, 725, https://doi.org/10.1007/s10661-018-7085-5, 2018.

Bennett, G. L., Miller, S. R., Roering, J. J., and Schmidt, D. A.: Landslides, threshold slopes, and the survival of relict terrain in the wake of the Mendocino Triple Junction, Geology, 44, 363–366, https://doi.org/10.1130/G37530.1, 2016.

Brenning, A., Schwinn, M., Ruiz-Páez, A. P., and Muenchow, J.: Landslide susceptibility near highways is increased by 1 order of magnitude in the Andes of southern Ecuador, Loja province, Nat. Hazards Earth Syst. Sci., 15, 45–57, https://doi.org/10.5194/nhess-15-45-2015, 2015.

Depicker, A., Jacobs, L., Delvaux, D., Havenith, H.-B., Maki Mateso, J.-C., Govers, G., and Dewitte, O.: The added value of a regional landslide susceptibility assessment: The western branch of the East African Rift, Geomorphology, 353, 106886, https://doi.org/10.1016/j.geomorph.2019.106886, 2020.

Depicker, A., Govers, G., Jacobs, L., Campforts, B., Uwihirwe, J., and Dewitte, O.: Interactions between deforestation, landscape rejuvenation, and shallow landslides in the North Tanganyika–Kivu rift region, Africa, Earth Surf. Dyn., 9, 445–462, https://doi.org/10.5194/esurf-9-445-2021, 2021.

Dewitte, O., Dille, A., Depicker, A., Kubwimana, D., Maki Mateso, J.-C., Mugaruka Bibentyo, T., Uwihirwe, J., and Monsieurs, E.: Constraining landslide timing in a data-scarce context: from recent to very old processes in the tropical environment of the North Tanganyika-Kivu Rift region, Landslides, 18, 161–177, https://doi.org/10.1007/s10346-020-01452-0, 2021.

Dewitte, O., Depicker, A., Moeyersons, J., and Dille, A.: Mass Movements in Tropical Climates, in: Treatise on Geomorphology, vol. 5, edited by: Shroder, J. J. F., Elsevier, 338–349, https://doi.org/10.1016/B978-0-12-818234-5.00118-8, 2022.

Dille, A., Kervyn, F., Mugaruka Bibentyo, T., Delvaux, D., Ganza, G. B., Ilombe Mawe, G., Kalikone Buzera, C., Safari Nakito, E., Moeyersons, J., Monsieurs, E., Nzolang, C., Smets, B., Kervyn, M., and Dewitte, O.: Causes and triggers of deep-seated hillslope instability in the tropics – Insights from a 60-year record of Ikoma landslide (DR Congo), Geomorphology, 345, 106835, https://doi.org/10.1016/j.geomorph.2019.106835, 2019.

Drake, T. W., Van Oost, K., Barthel, M., Bauters, M., Hoyt, A. M., Podgorski, D. C., Six, J., Boeckx, P., Trumbore, S. E., Cizungu Ntaboba, L., and Spencer, R. G. M.: Mobilization of aged and biolabile soil carbon by tropical deforestation, Nat. Geosci., 12, 541–546, https://doi.org/10.1038/s41561-019-0384-9, 2019.

Fisher, G. B., Amos, C. B., Bookhagen, B., Burbank, D. W., and Godard, V.: Channel widths, landslides, faults, and beyond: The new world order of high-spatial resolution Google Earth imagery in the study of earth surface processes, in: Google Earth and Virtual Visualizations in Geoscience Education and Research, vol. 492, Geological Society of America, 1–22, https://doi.org/10.1130/2012.2492(01), 2012.

Froude, M. J. and Petley, D. N.: Global fatal landslide occurrence from 2004 to 2016, Nat. Hazards Earth Syst. Sci., 18, 2161–2181, https://doi.org/10.5194/nhess-18-2161-2018, 2018.

Geenen, S.: A dangerous bet: The challenges of formalizing artisanal mining in the Democratic Republic of Congo, Resour. Policy, 37, 322–330, https://doi.org/10.1016/j.resourpol.2012.02.004, 2012.

Hungr, O., Leroueil, S., and Picarelli, L.: The Varnes classification of landslide types, an update, Landslides, 11, 167–194, https://doi.org/10.1007/s10346-013-0436-y, 2014.

Jacobs, L., Dewitte, O., Poesen, J., Sekajugo, J., Nobile, A., Rossi, M., Thiery, W., and Kervyn, M.: Field-based landslide susceptibility assessment in a data-scarce environment: the populated areas of the Rwenzori Mountains, Nat. Hazards Earth Syst. Sci., 18, 105–124, https://doi.org/10.5194/nhess-18-105-2018, 2018.

Jaillon, A.: Maps of conflict minerals in eastern DRC - A0 posters (International Peace Information Service, Accessed September 25, 2020), 2020.

Jones, J. N., Boulton, S. J., Stokes, M., Bennett, G. L., and Whitworth, M. R. Z.: 30-year record of Himalaya mass-wasting reveals landscape perturbations by extreme events, Nat. Commun., 12, 6701, https://doi.org/10.1038/s41467-021-26964-8, 2021.

Keefer, D. K.: Landslides caused by earthquakes., Geol. Soc. Am. Bull., 95, 406–421, https://doi.org/https://doi.org/10.1130/0016-7606(1984)95, 1984.

Kubwimana, D., Ait Brahim, L., Nkurunziza, P., Dille, A., Depicker, A., Nahimana, L., Abdelouafi, A., and Dewitte, O.: Characteristics and Distribution of Landslides in the Populated Hillslopes of Bujumbura, Burundi, Geosciences, 11, 259, https://doi.org/10.3390/geosciences11060259, 2021.

Maki Mateso, J.-C. and Dewitte, O.: Towards an inventory of landslide processes and the elements at risk on the Rift flanks West of Lake Kivu (DRC), Geo. Eco. Trop., 38, 137–154, 2014.

McAdoo, B. G., Quak, M., Gnyawali, K. R., Adhikari, B. R., Devkota, S., Rajbhandari, P. L., and Sudmeier-Rieux, K.: Roads and landslides in Nepal: how development affects environmental risk, Nat. Hazards Earth Syst. Sci., 18, 3203–3210, https://doi.org/10.5194/nhess-18-3203-2018, 2018.

Monsieurs, E., Jacobs, L., Michellier, C., Basimike Tchangaboba, J., Ganza, G. B., Kervyn, F., Maki Mateso, J.-C., Mugaruka Bibentyo, T., Kalikone Buzera, C., Nahimana, L., Ndayisenga, A., Nkurunziza, P., Thiery, W., Demoulin, A., Kervyn, M., and Dewitte, O.: Landslide inventory for hazard assessment in a data-poor context: a regional-scale approach in a tropical African environment, Landslides, 15, 2195–2209, https://doi.org/10.1007/s10346-018-1008-y, 2018.

Muñoz-Torrero Manchado, A., Allen, S., Ballesteros-Cánovas, J. A., Dhakal, A., Dhital, M. R., and Stoffel, M.: Three decades of landslide activity in western Nepal: new insights into trends and climate drivers, Landslides, 18, 2001–2015, https://doi.org/10.1007/s10346-021-01632-6, 2021.

Musumba Teso, P., Kavira, M., and Katcho, K.: Key Factors Driving Deforestation in North-Kivu Province, Eastern DR-Congo Using GIS and Remote Sensing, Am. J. Geogr. Inf. Syst., 8, 11–25, https://doi.org/10.5923/j.ajgis.20190801.02, 2019.

Pánek, T., Břežný, M., Kilnar, J., and Winocur, D.: Complex causes of landslides after ice sheet retreat: Post-LGM mass movements in the Northern Patagonian Icefield region, Sci. Total Environ., 758, 143684, https://doi.org/10.1016/j.scitotenv.2020.143684, 2021.

Prakash, N., Manconi, A., and Loew, S.: A new strategy to map landslides with a generalized convolutional neural network, Sci. Rep., 11, 9722, https://doi.org/10.1038/s41598-021-89015-8, 2021.

Reichenbach, P., Rossi, M., Malamud, B. D., Mihir, M., and Guzzetti, F.: A review of statistically-based landslide susceptibility models, Earth-Science Rev., 180, 60–91, https://doi.org/10.1016/j.earscirev.2018.03.001, 2018.

Sidle, R. C. and Bogaard, T. A.: Dynamic earth system and ecological controls of rainfall-initiated landslides, Earth-Science Rev., 159, 275–291, https://doi.org/10.1016/j.earscirev.2016.05.013, 2016.

Sidle, R. C., Ziegler, A. D., Negishi, J. N., Nik, A. R., Siew, R., and Turkelboom, F.: Erosion processes in steep terrain—Truths, myths, and uncertainties related to forest management in Southeast Asia, For. Ecol. Manage., 224, 199–225, https://doi.org/10.1016/j.foreco.2005.12.019, 2006.

Tanyaş, H., Allstadt, K. E., and van Westen, C. J.: An updated method for estimating landslide-event magnitude, Earth Surf. Process. Landforms, 43, 1836–1847, https://doi.org/10.1002/esp.4359, 2018.

Tanyaş, H., Görüm, T., Kirschbaum, D., and Lombardo, L.: Could road constructions be more hazardous than an earthquake in terms of mass movement?, Nat. Hazards, 112, 639–663, https://doi.org/10.1007/s11069-021-05199-2, 2022.

Van Acker, F.: Where did all the land go? Enclosure & social struggle in Kivu (D.R.Congo), Rev. Afr. Polit. Econ., 32, 79–98, https://doi.org/10.1080/03056240500120984, 2005.

Vanacker, V., Vanderschaeghe, M., Govers, G., Willems, E., Poesen, J., Deckers, J., and De Bievre, B.: Linking hydrological, infinite slope stability and land-use change models through GIS for assessing the impact of deforestation on slope stability in high Andean watersheds, Geomorphology, 52, 299–315, https://doi.org/10.1016/S0169-555X(02)00263-5, 2003.

Vuillez, C., Tonini, M., Sudmeier-Rieux, K., Devkota, S., Derron, M.-H., and Jaboyedoff, M.: Land use changes, landslides and roads in the Phewa Watershed, Western Nepal from 1979 to 2016, Appl. Geogr., 94, 30–40, https://doi.org/10.1016/j.apgeog.2018.03.003, 2018.

Whipple, K. X.: The influence of climate on the tectonic evolution of mountain belts, Nat. Geosci., 2, 97–104, https://doi.org/10.1038/ngeo413, 2009.

Whittaker, A. C.: How do landscapes record tectonics and climate?, Lithosphere, 4, 160–164, https://doi.org/10.1130/RF.L003.1, 2012.